Mach Stability Improvements Using an Existing Second Throat Capability at the National Transonic Facility

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Outline

Introduction

Experimental Setup

Results

- Sonic conditions at second throat
- Mach number variability
- Correlation between Mach number and drag
- Consequences of using existing second throat

Summary and Concluding Remarks

NTF Data Quality Improvements

Recent upgrades aimed at improving overall data quality at NTF

Improve Mach stability in transonic regime

- Decrease pressure fluctuations in test section for $M_\infty \geq 0.8$
- Correlation between Mach and drag in drag divergence region
- Reduction in Mach variability ➔ Drag repeatability improvements

Goals

- $M_\infty \pm 0.0005$ (Current capability : ±0.001)
- Repeatability : $C_D \pm 0.5$ counts for full-span transport models

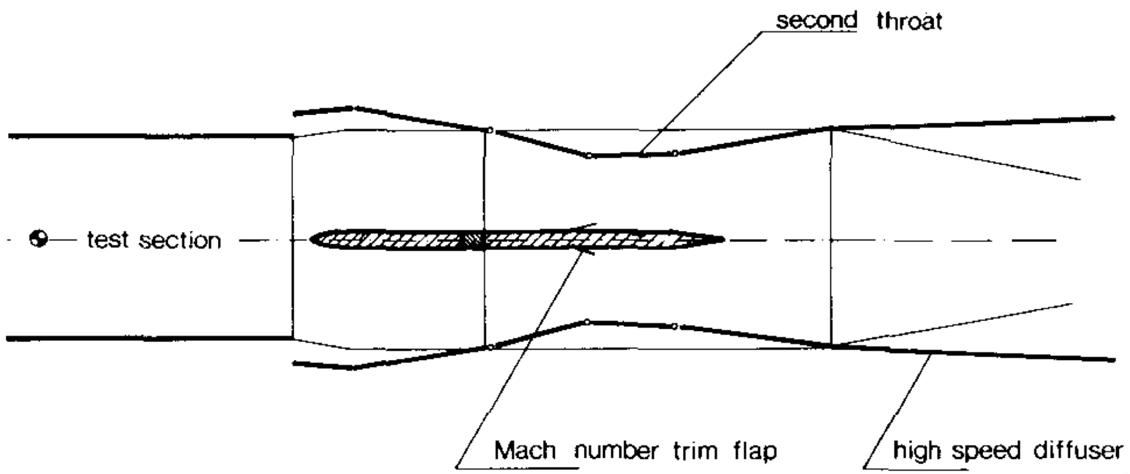
3-prong approach

1. Second throat
2. Conditional sampling
3. Control system improvements

Second Throats in Transonic Tunnels

Use of second throats in transonic wind tunnels is common

- Effective in preventing upstream propagation of acoustic disturbances from downstream sources such as the high-speed diffuser
- Also used for fine Mach number control during model traverses
- Typically located downstream of the test section and arc sector



Examples

- NASA LaRC 8-foot Transonic Pressure Tunnel
- European Transonic Windtunnel (ETW)

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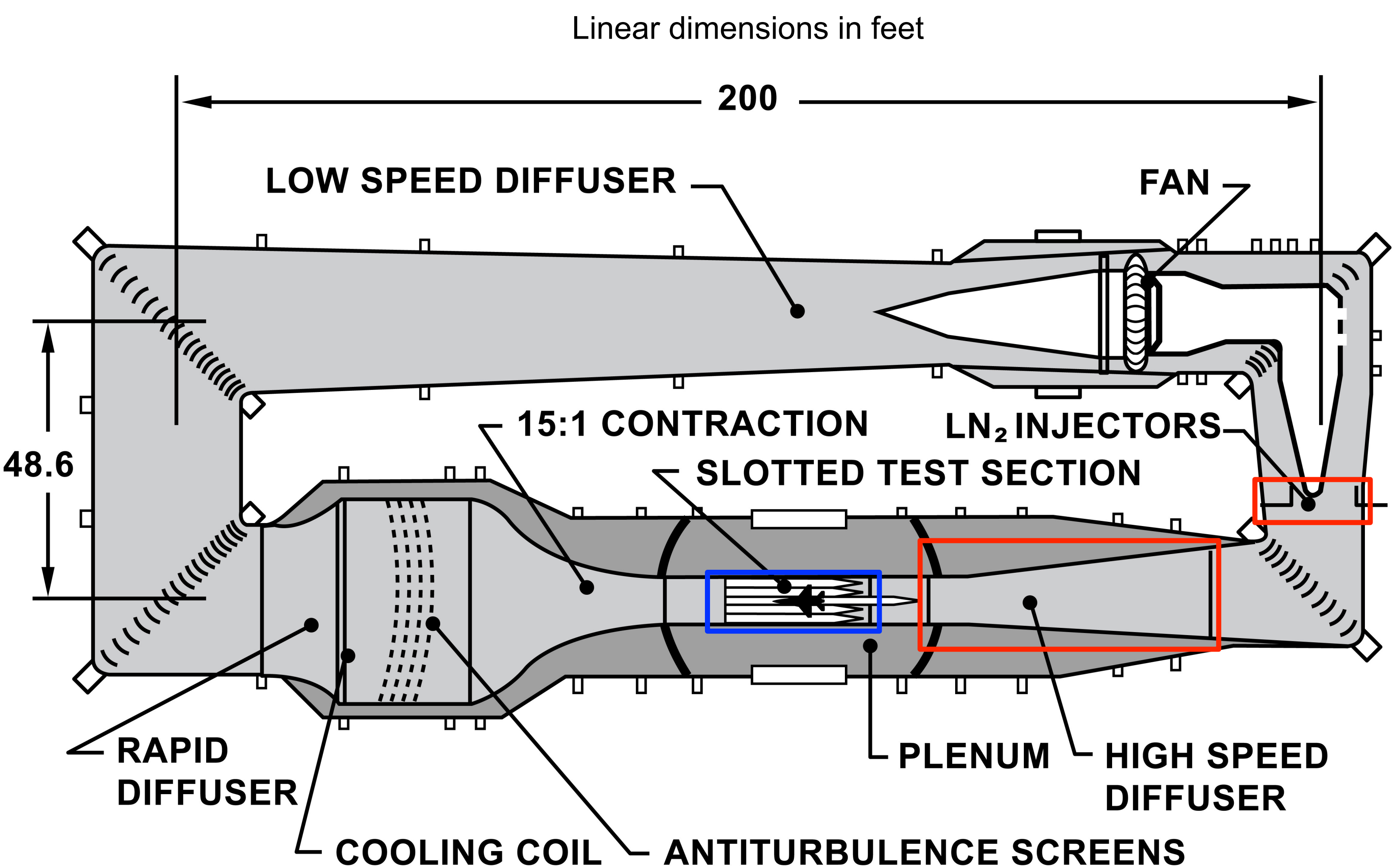
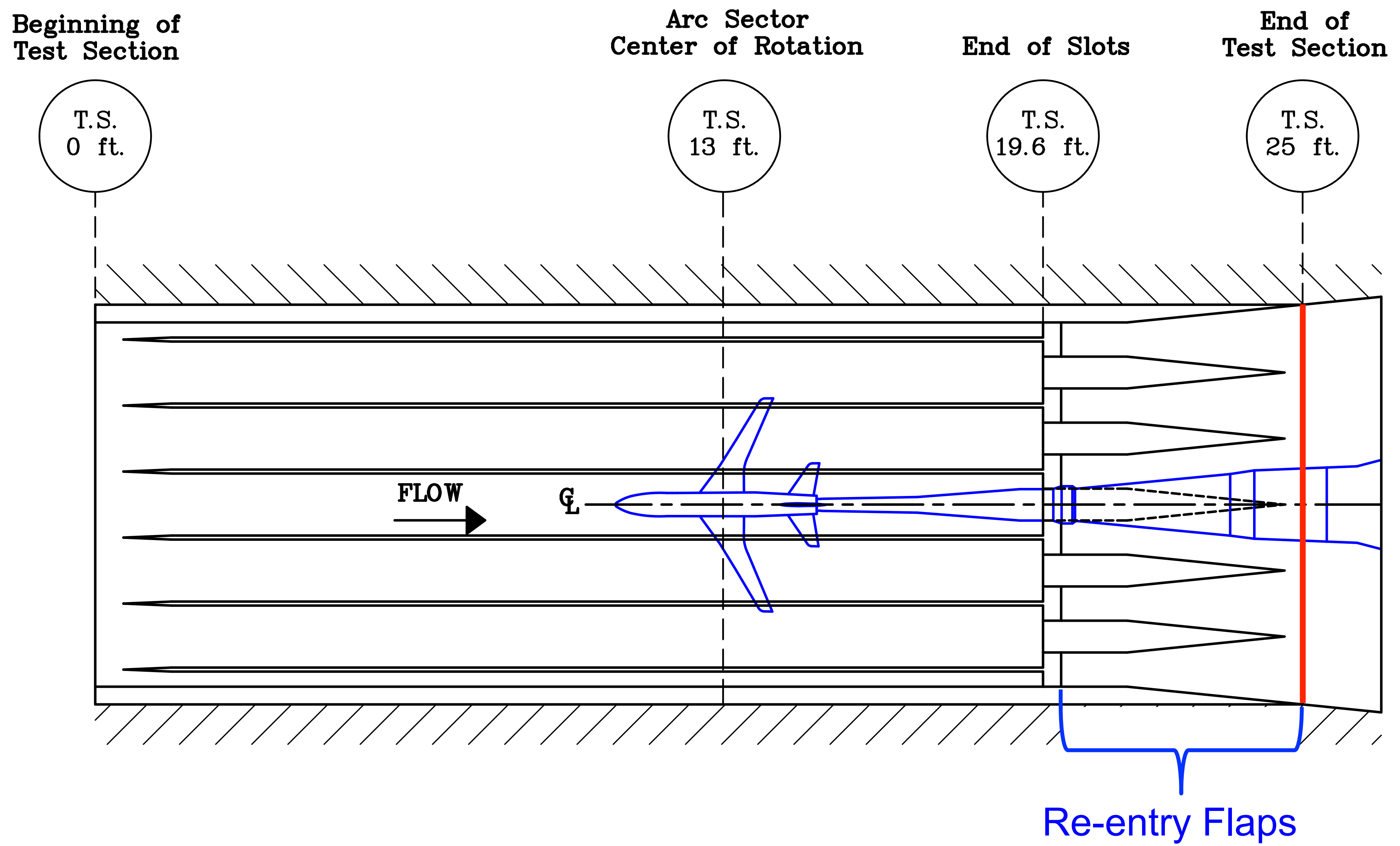
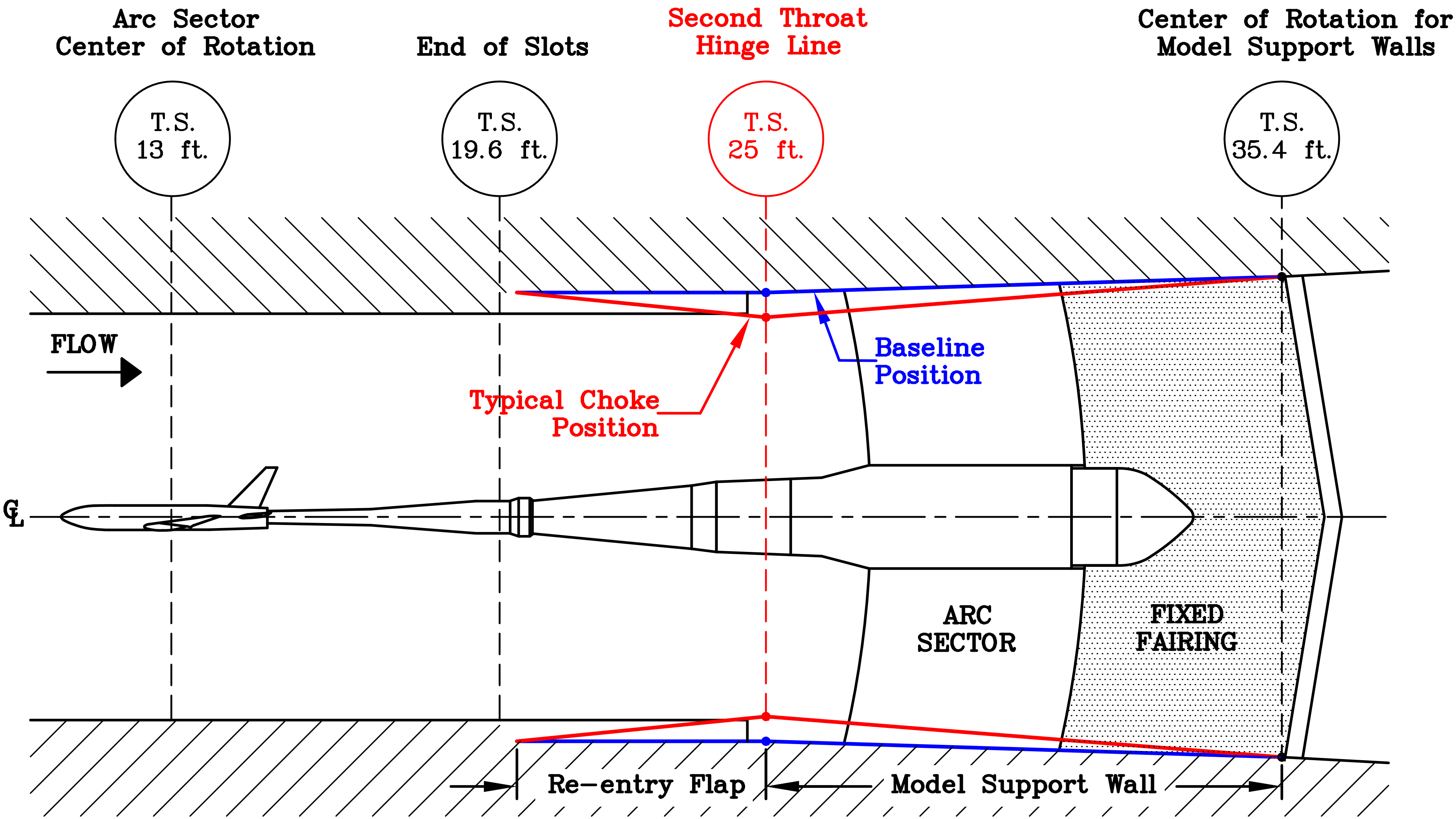
Cryogenic, pressurized wind tunnel capable of achieving very high Reynolds numbers (flight Re for transport type aircraft)



NTF Test Section

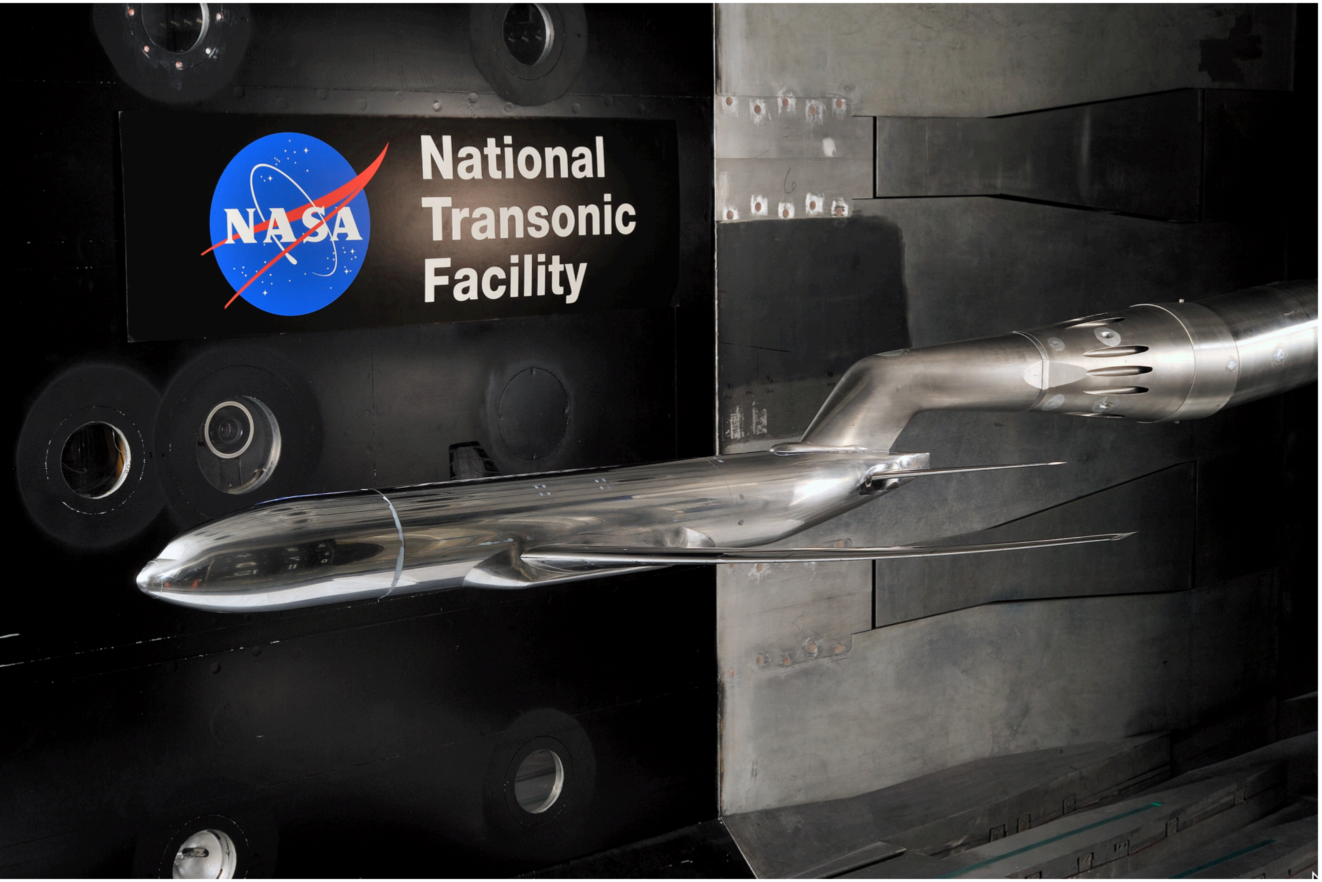


Existing Second Throat Capability



Combination of re-entry flaps and model support walls to set minimum area at end of test section (T.S. 25 ft.)

2.7%-scale Common Research Model (CRM) tested in NTF



Design Conditions:

$M_\infty = 0.85$

$C_L = 0.50$

Wing Parameters:

AR = 9.0

35° LE sweep

$S_{ref} = 3.01\ ft^2$

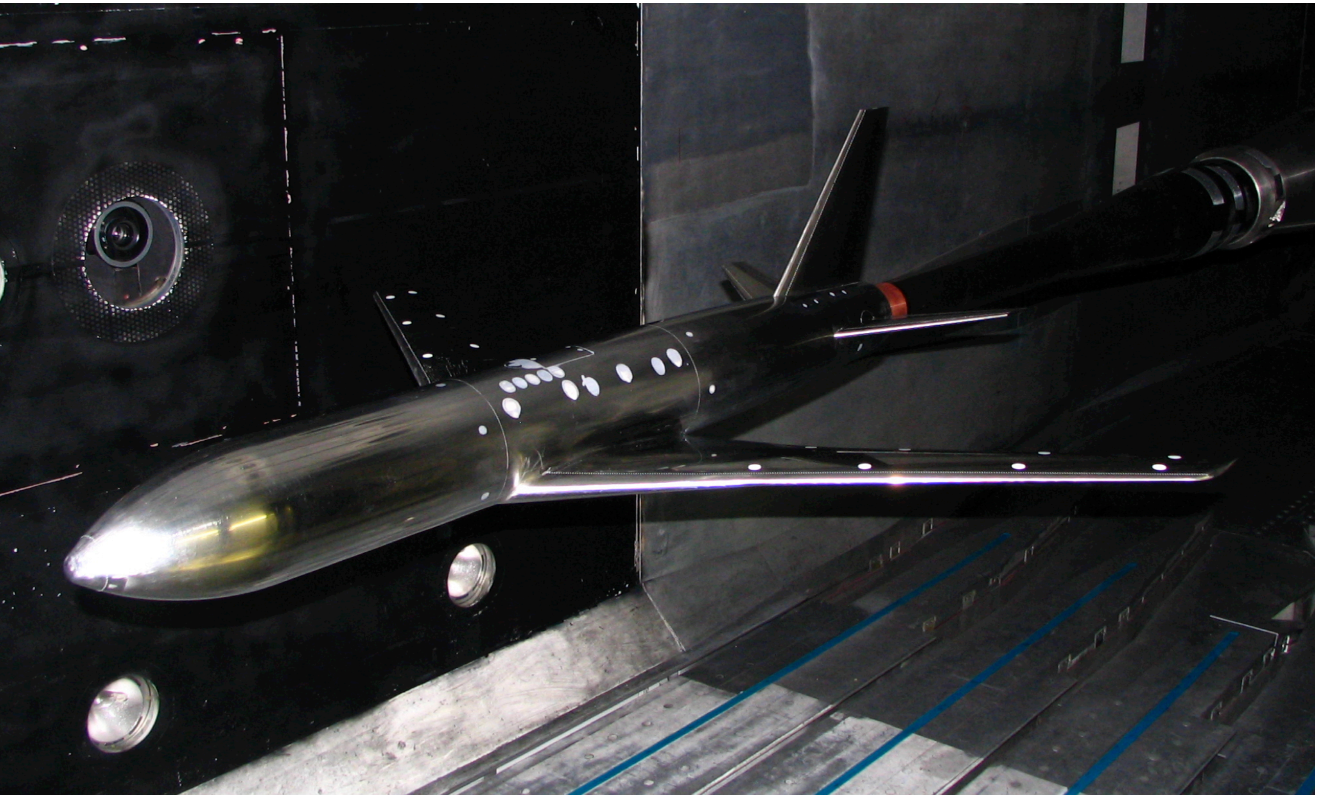
Span = 62.47 in.

MAC = 7.45 in.

$\lambda = 0.275$

NTF Pathfinder-I Model (PF-I)

Full-scale Pathfinder-I Model (PF-I) tested in NTF



Design Conditions:

$M_\infty = 0.82$

$C_L = 0.55$

Wing Parameters:

AR = 9.8

35° LE sweep

$S_{ref} = 1.988\ ft^2$

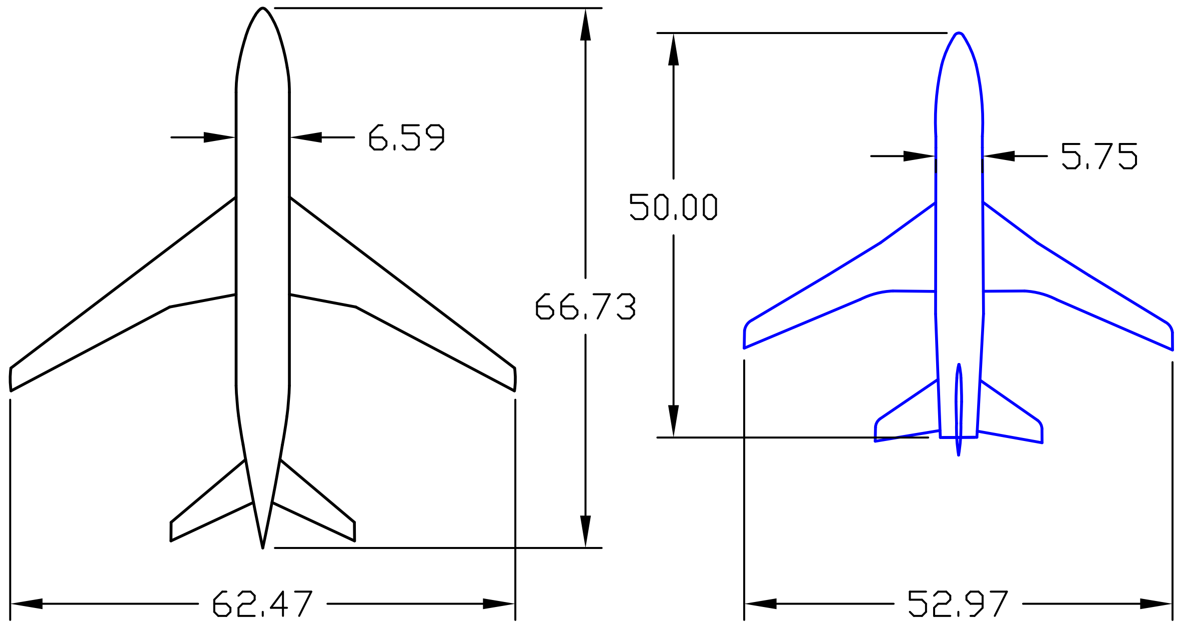
Span = 52.97 in.

MAC = 5.74 in.

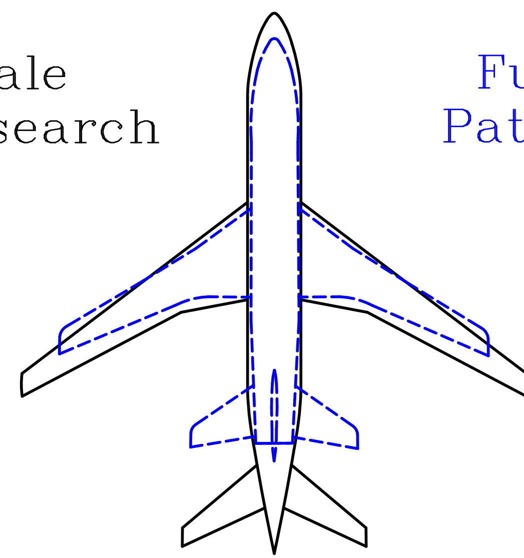
$\lambda = 0.313$

Comparison between CRM and PF-I models

Linear dimensions in inches



0.027-scale Common Research Model

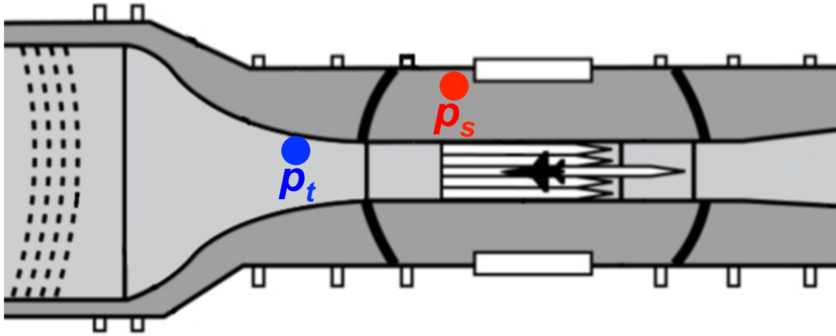


Full-scale Pathfinder-I Model

M_∞ = 0.85

Blockage	CRM	PF-I
Solid	2.20%	1.70%
Wake	0.06%	0.07%
Total	**2.26%**	**1.77%**

Experimental Measurements



Mach number measurement

- Total pressure in contraction
- Static pressure in plenum
- p_t, p_s, T_t ➔ M_{ref}
  - M_{ref} corrected to M_∞ by tunnel calibration

Force and moment measurements

- NTF-118A internal balance (cryogenic, 6-component)

Data system

- Standard
- Dynamic (high sampling)

DAS	Sampling Frequency	Sampling Period
Standard	400 Hz	12 sec
Dynamic	12,800 Hz	12 sec

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Transonic Results

Tunnel configuration

- Baseline
- Second throat set to fully choke for $M_\infty = 0.9$

CRM data

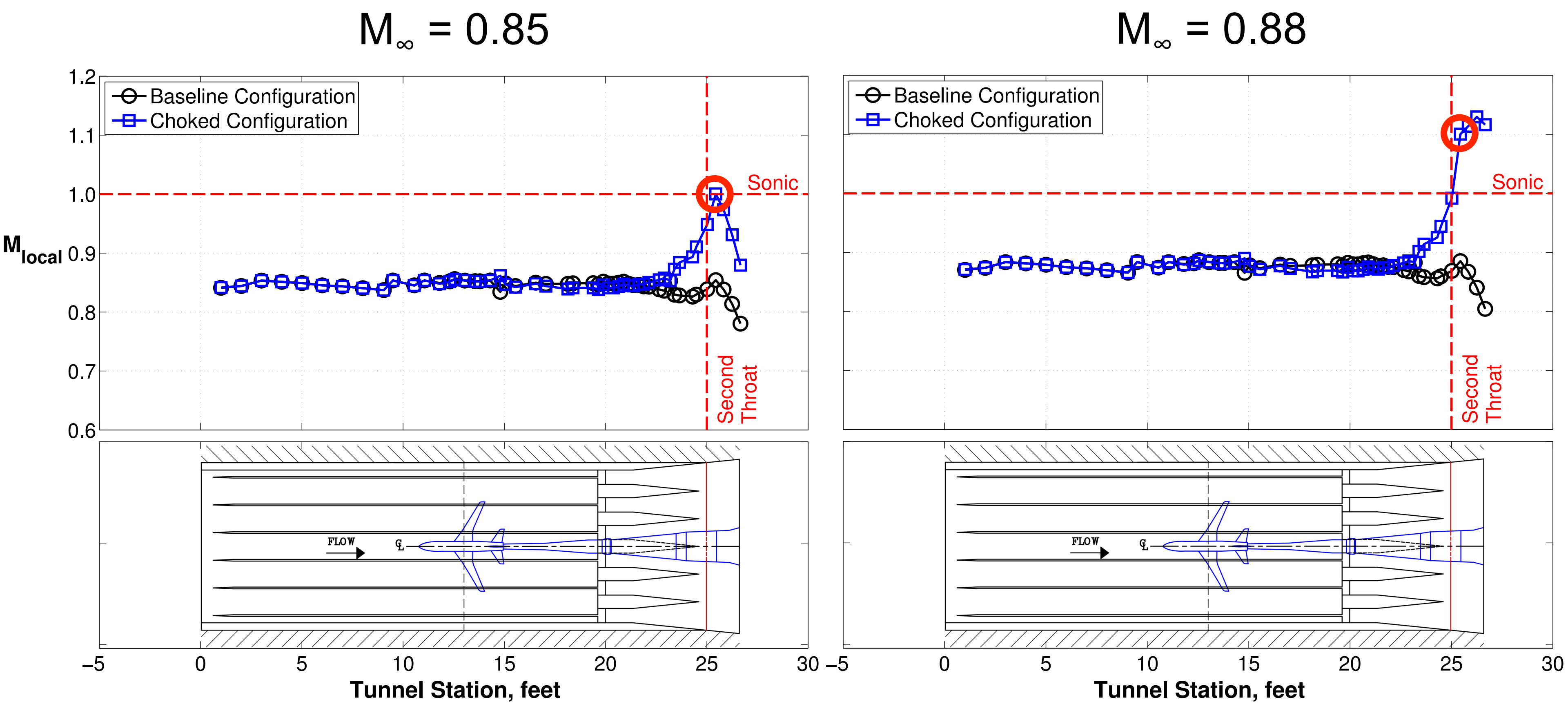
- $M_\infty = 0.70, 0.85, 0.87$
- $Re_c = 5, 10, 19.8$ million
- $T_t = 120°F, -50°F, -250°F$
- $\alpha = -3°$ to $5°$

PF-I data

- $M_\infty = 0.70, 0.75, 0.80, 0.82, 0.84, 0.85, 0.86, 0.87, 0.88$
- $Re_c = 2.5$ million
- $T_t = 120°F$
- $\alpha = -2°$ to $5°$

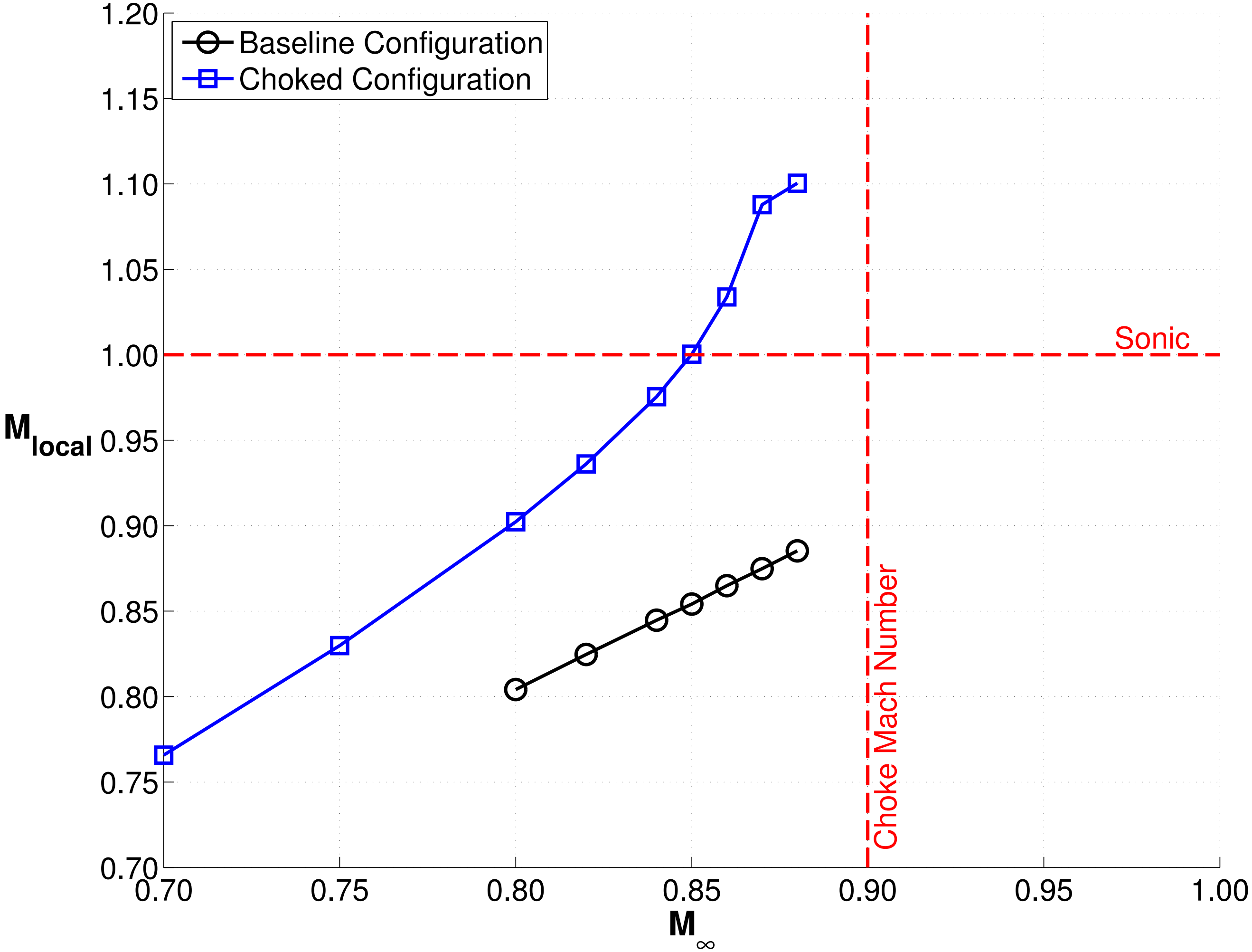
Local Mach number on sidewall row 9 from PF-I test

- Baseline vs. Choked tunnel configuration



Local Mach number at T.S. 25.44 ft. on sidewall row 9 from PF-I test

- Baseline vs. Choked tunnel configuration



For choke Mach number of 0.9, sonic condition achieved at second throat for $M_\infty \geq 0.85$

Strength of shock at second throat increases as M_∞ approaches choke Mach number

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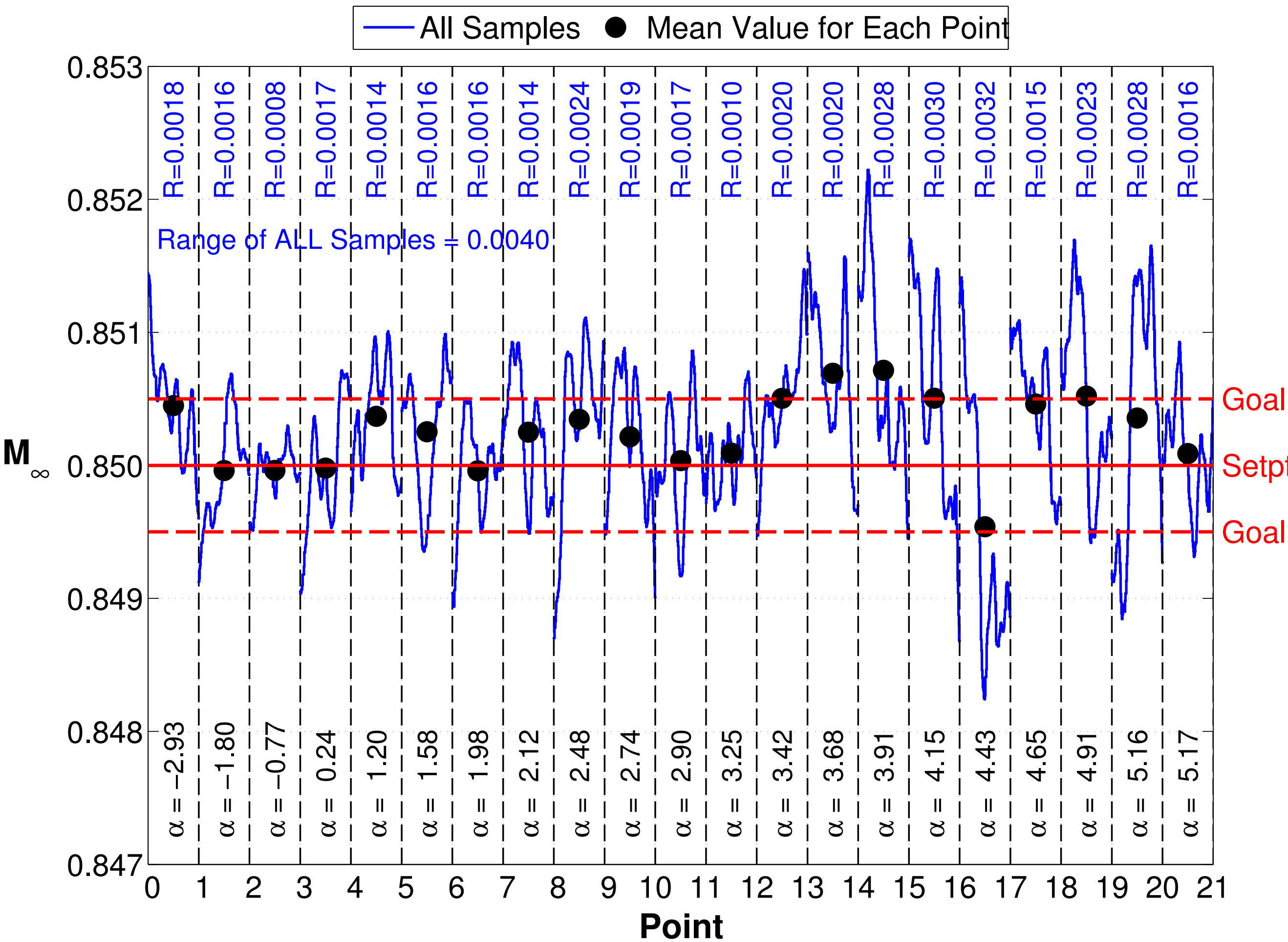
M_∞ = 0.85 in BASELINE tunnel configuration from CRM test

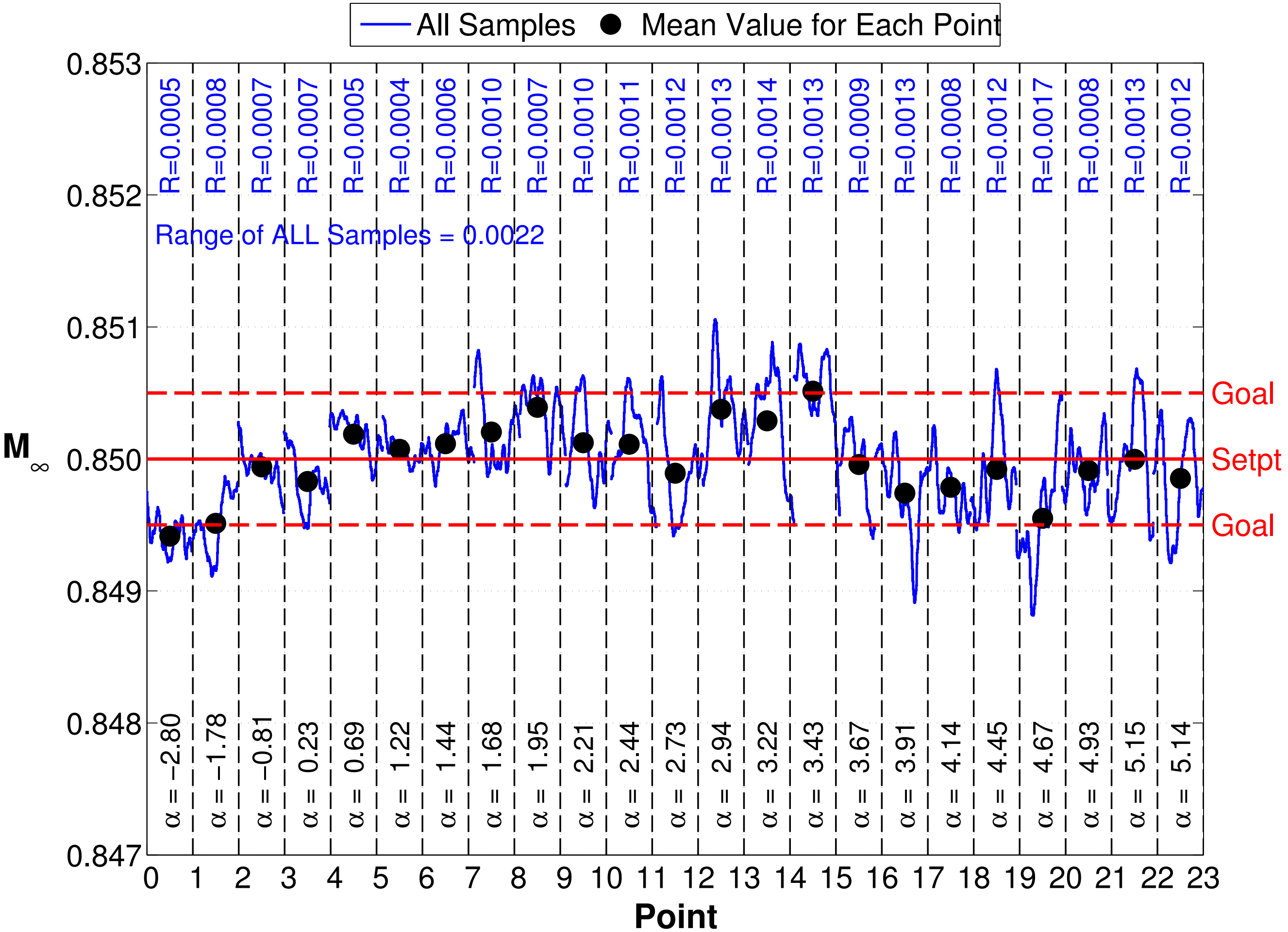


Range (R) = Max - Min

Variation within a data point is sometimes large especially for higher angles of attack

Some mean values are NOT within goal limits

M_∞ = 0.85 in CHOKED tunnel configuration from CRM test

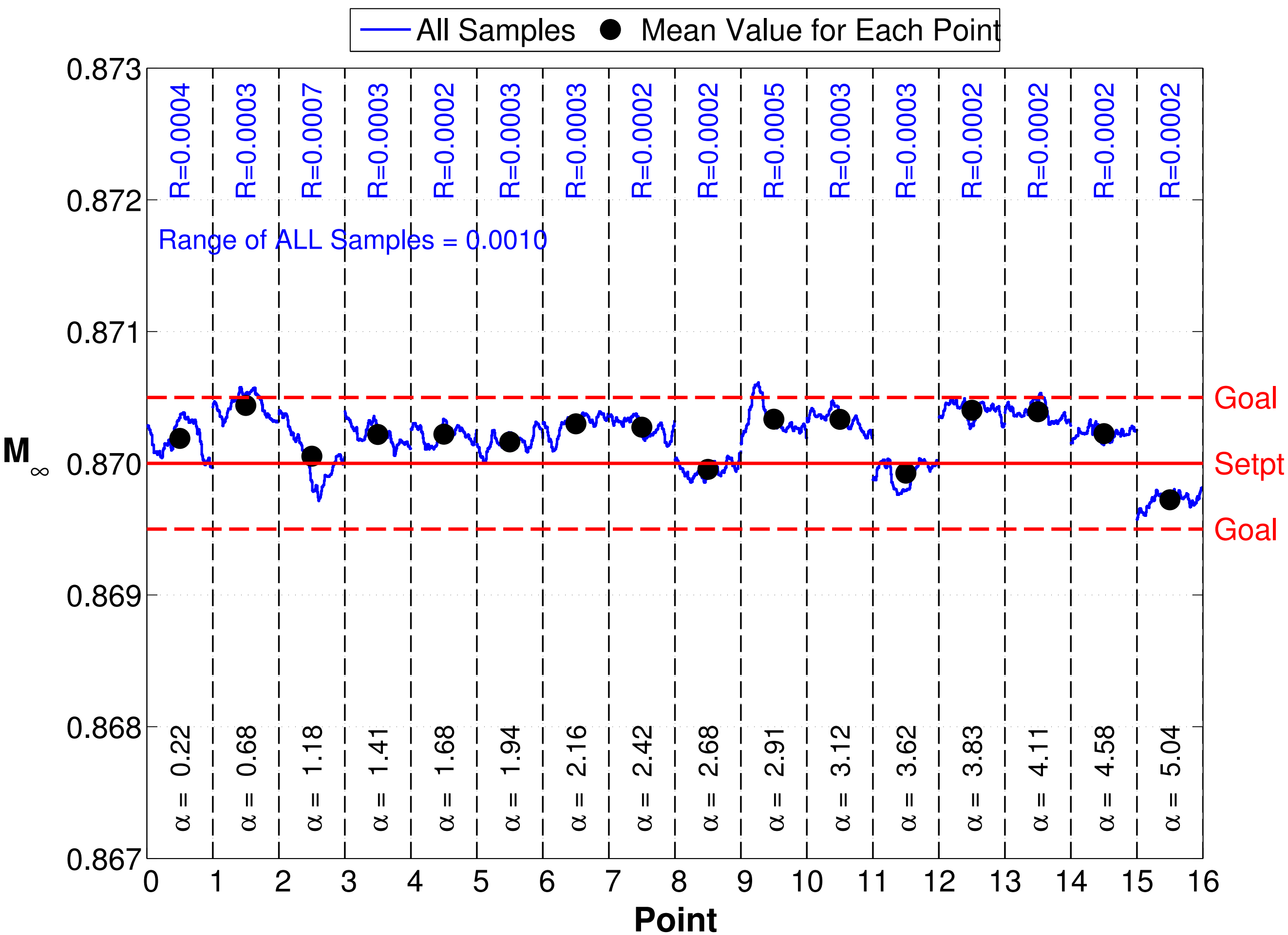


Variation within a data point is reduced for all angles of attack

Almost all mean values are within goal limits

Mach Number Variability

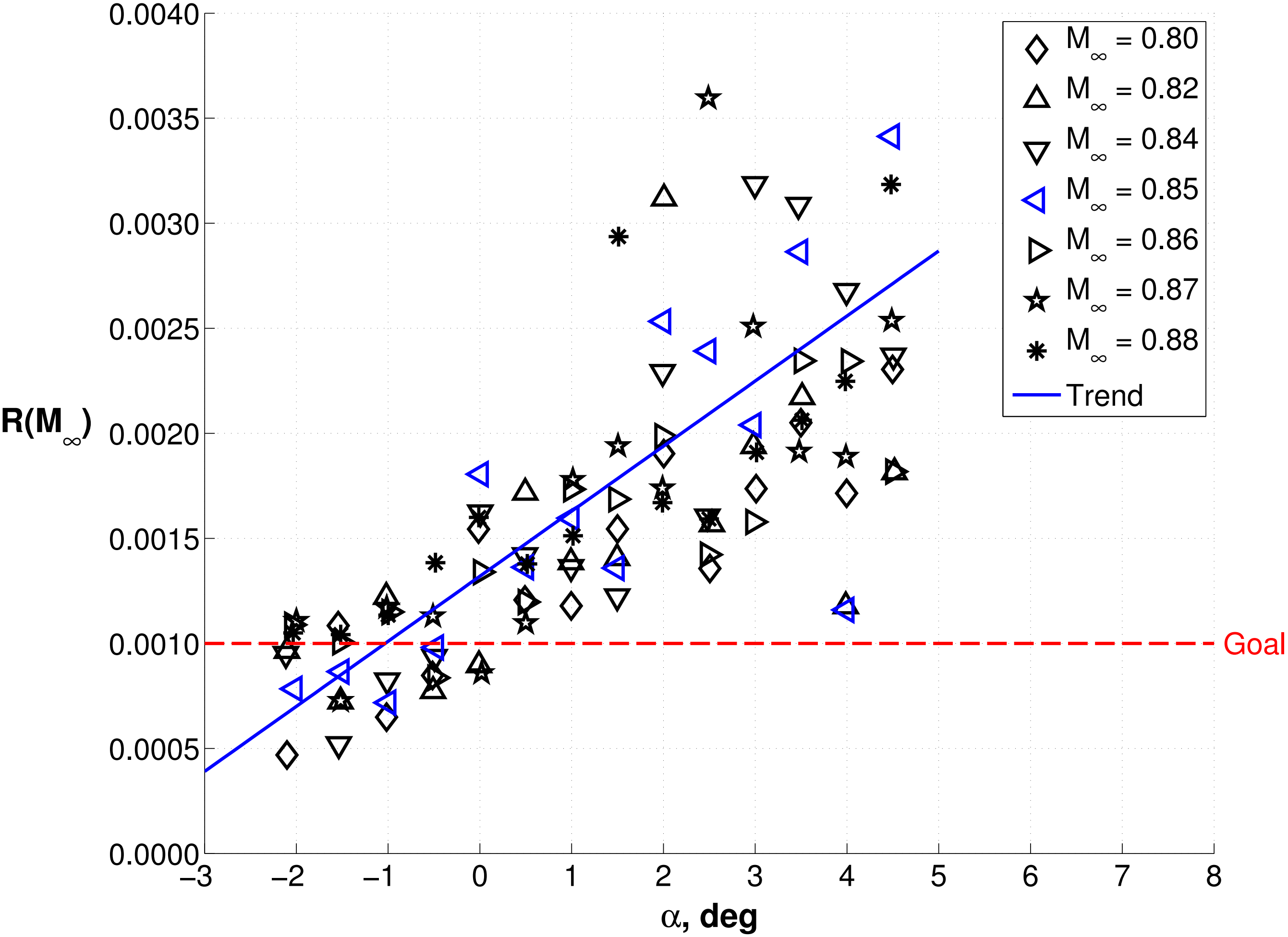
M_∞ = 0.87 in CHOKED tunnel configuration from CRM test



Variation within a data point is significantly reduced as M_∞ approaches choke Mach number

ALL mean values are within goals

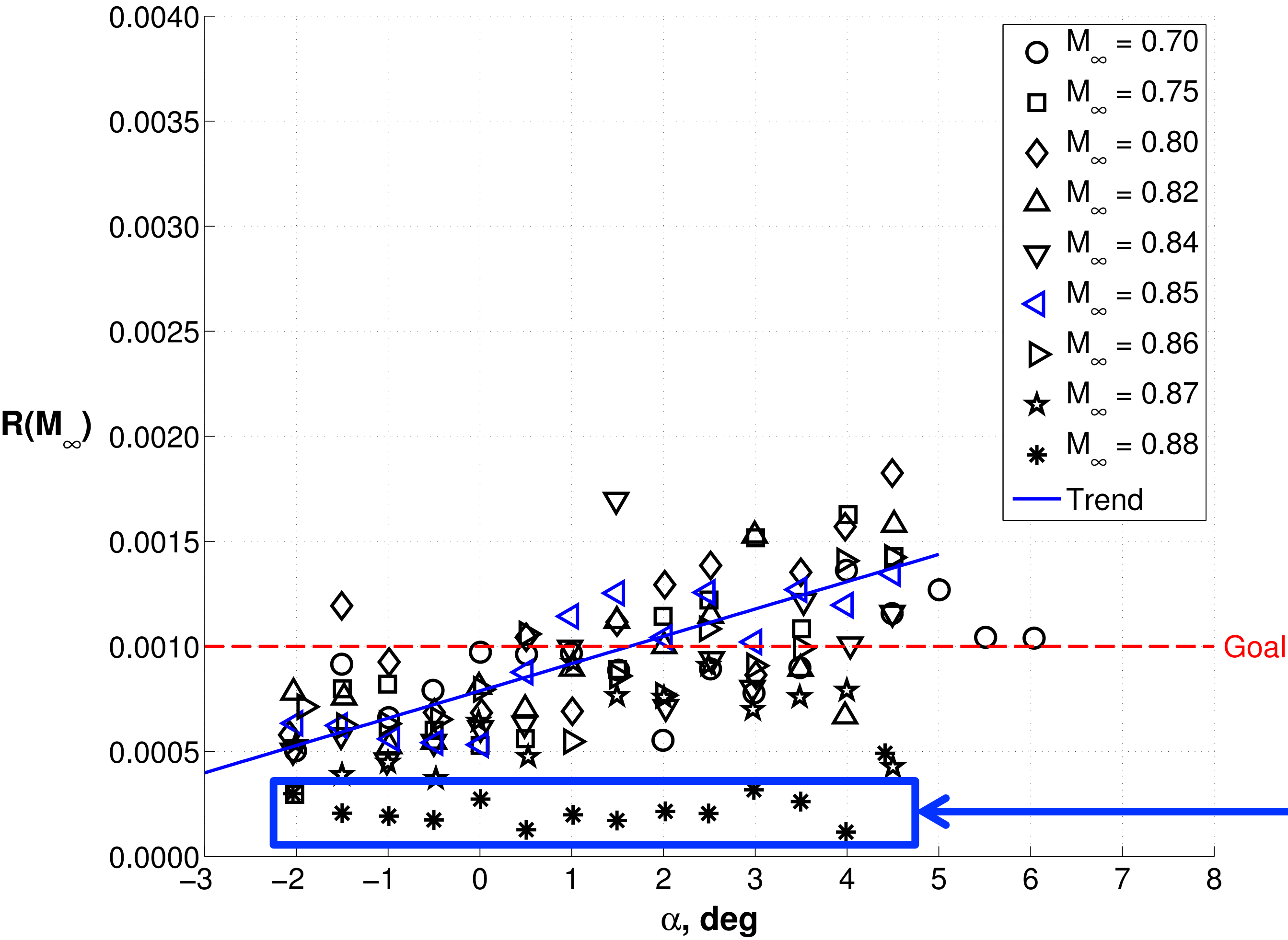
Variation as a function of angle of attack in <u>BASELINE</u> tunnel configuration from PF-I test



Range (R) = Max - Min

Upward trend of Mach variation with angle of attack at all Mach numbers

Variation as a function of angle of attack in CHOKED tunnel configuration from PF-I test



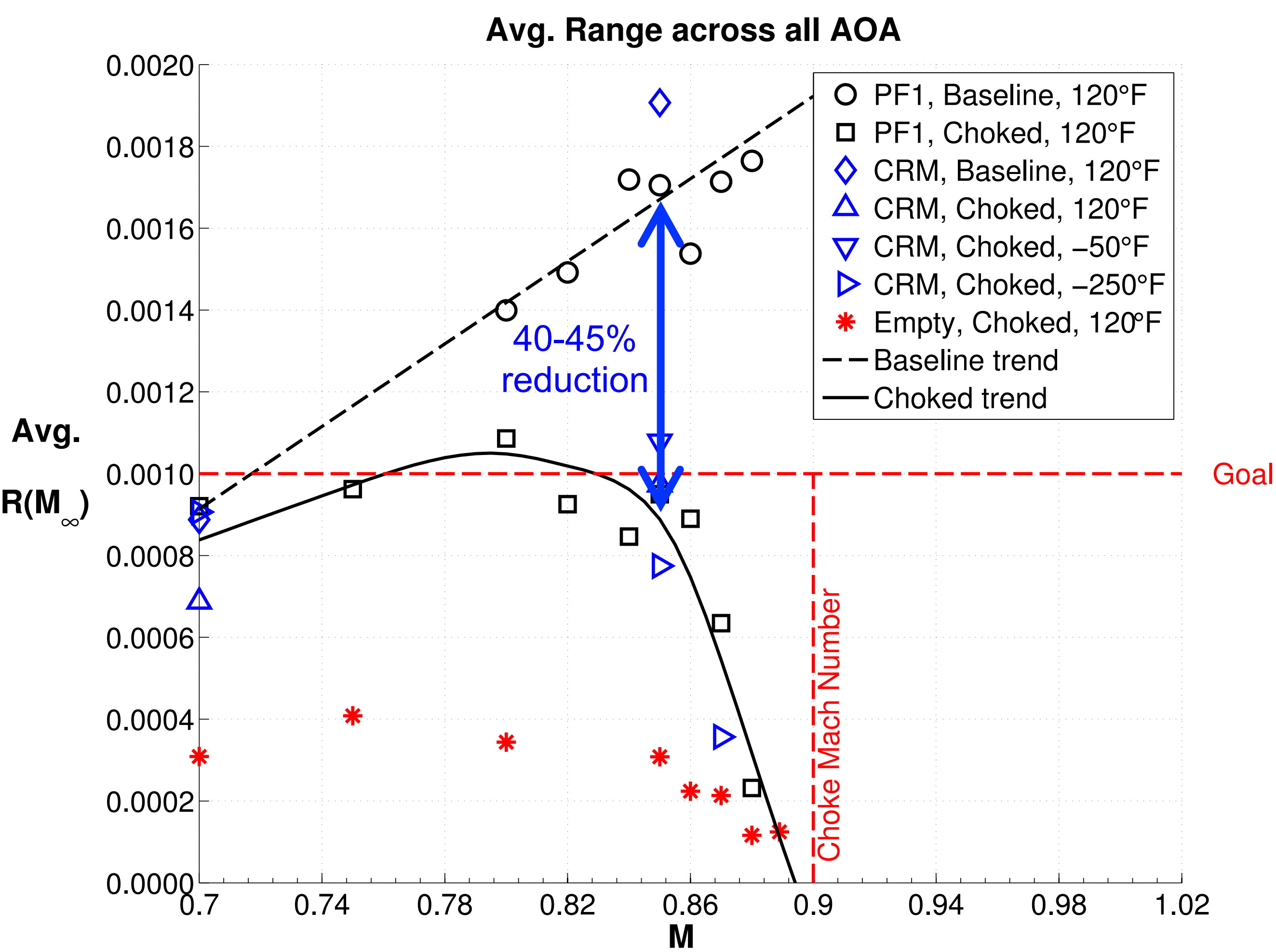
Overall variation levels reduced for all Mach numbers

Trend with angle of attack also reduced for all Mach numbers

Trend with angle of attack eliminated completely at $M_\infty = 0.88$

Mach Number Variability

Variation as a function of M_∞ from CRM and PF-I tests



In BASELINE tunnel configuration, variation increases with M_∞

In CHOKED tunnel configuration, variation decreases rapidly as M_∞ approaches choke Mach number

40-45% reduction in variation levels at $M_\infty = 0.85$

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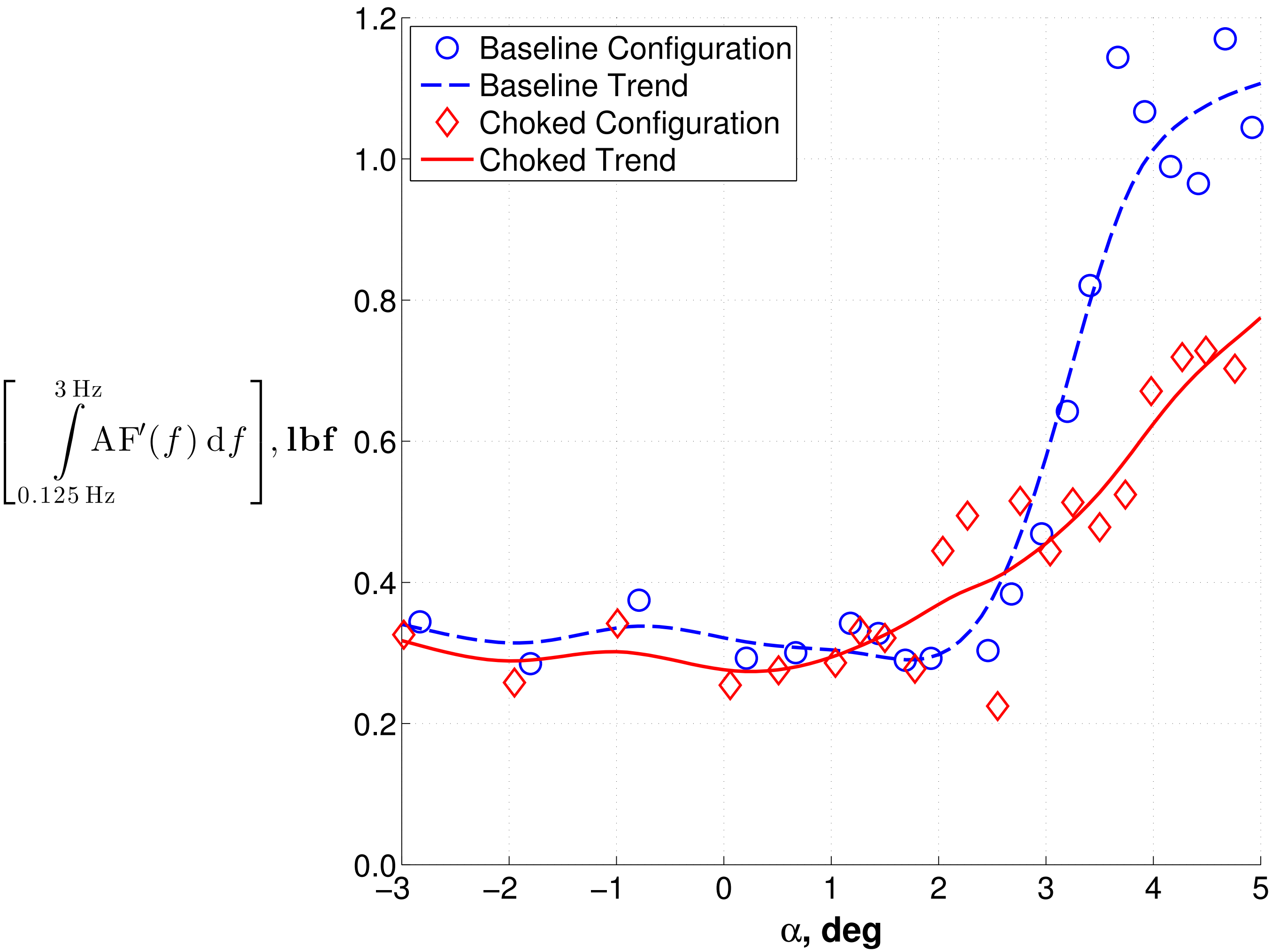
Correlation Between Mach and Drag

M_∞ = 0.85 from CRM test



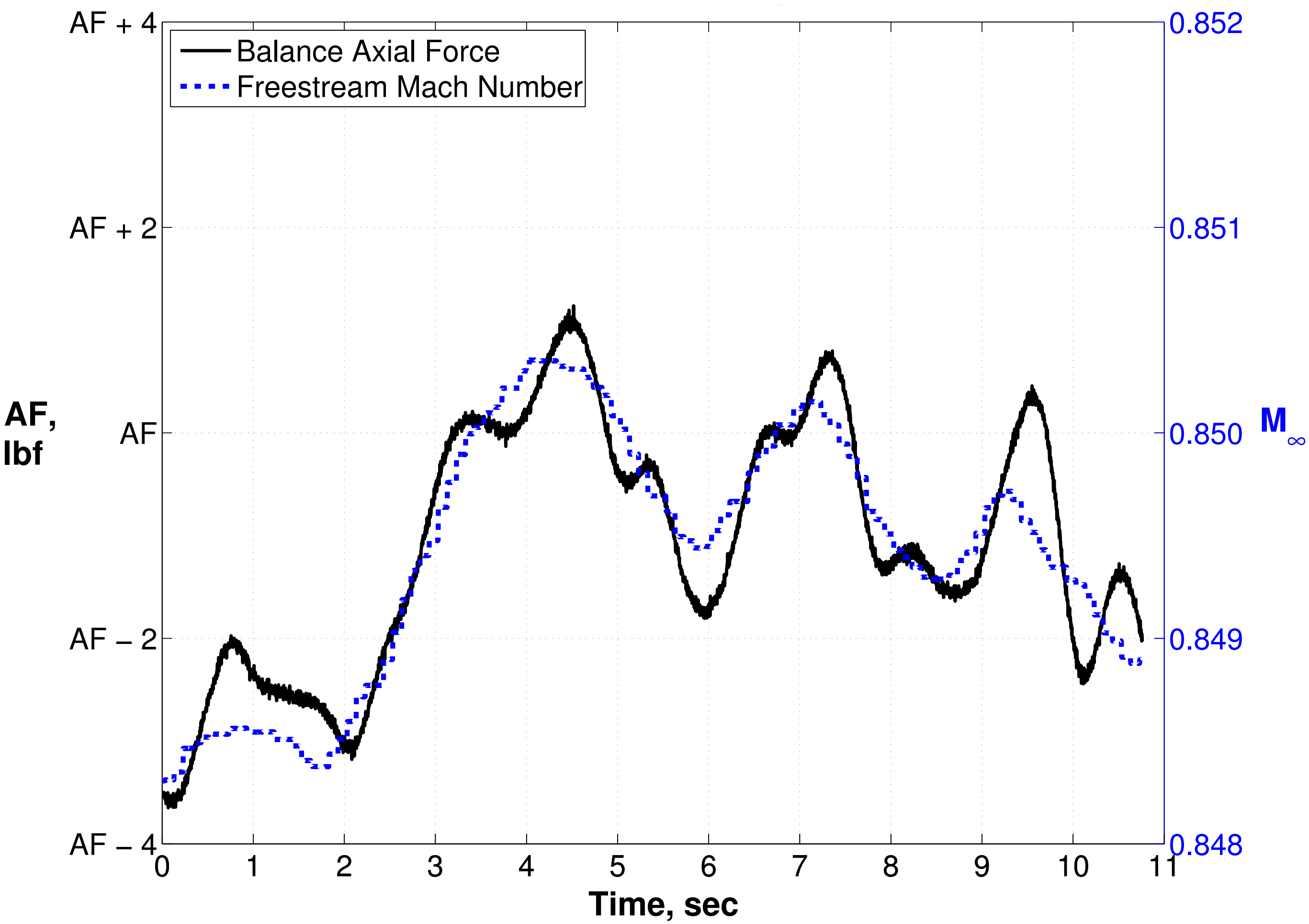
Model wake drives low frequency disturbances in the tunnel

Disturbances increase with angle of attack and adversely affect Mach stability

In the CHOKED tunnel configuration, the low frequency balance axial force fluctuations were reduced, similar to Mach variability results

Correlation Between Mach and Drag

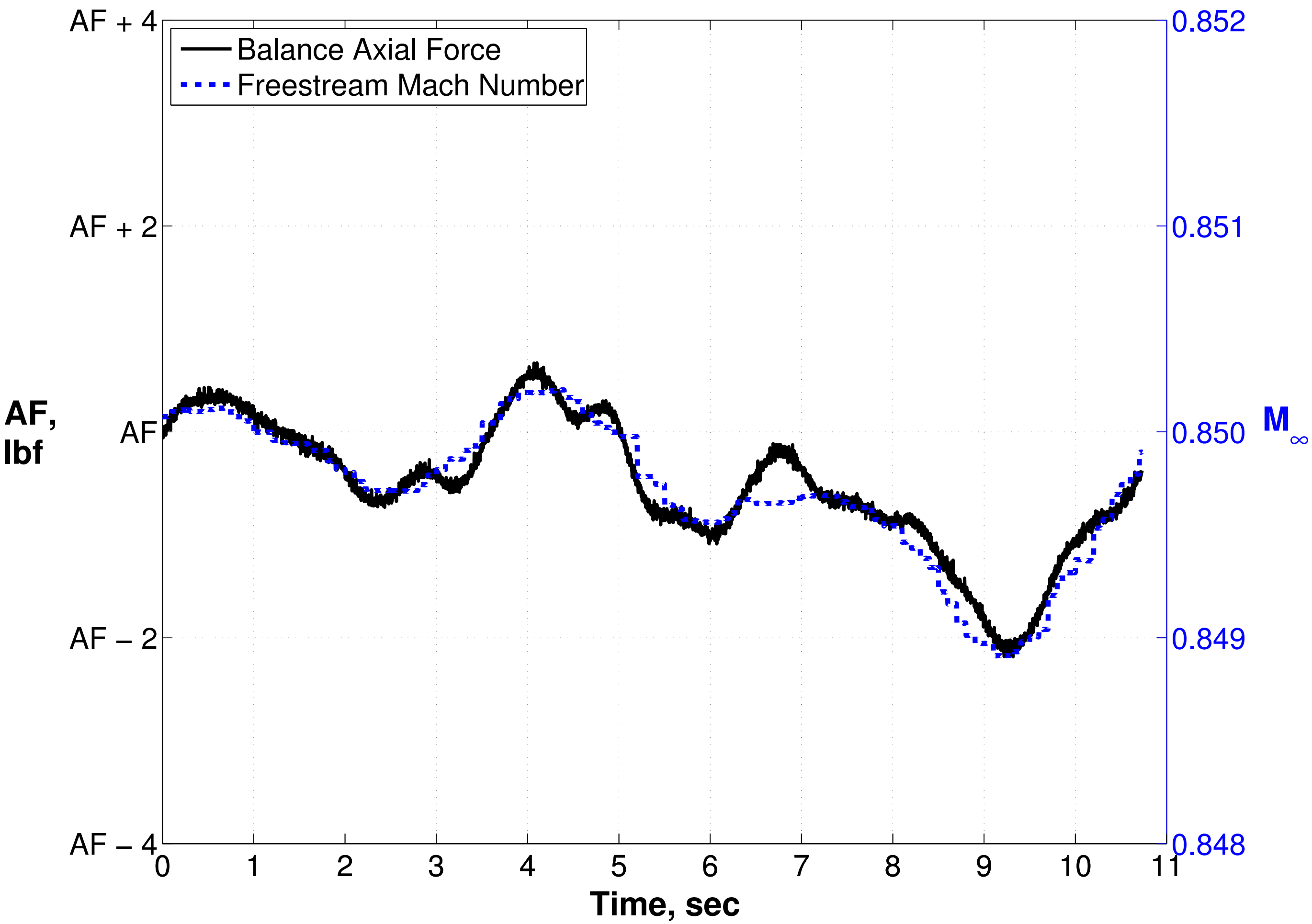
M_∞ = 0.85 at α=4° in <u>BASELINE</u> tunnel configuration from CRM test



Strong correlation between M_∞ and balance axial force

Correlation Between Mach and Drag

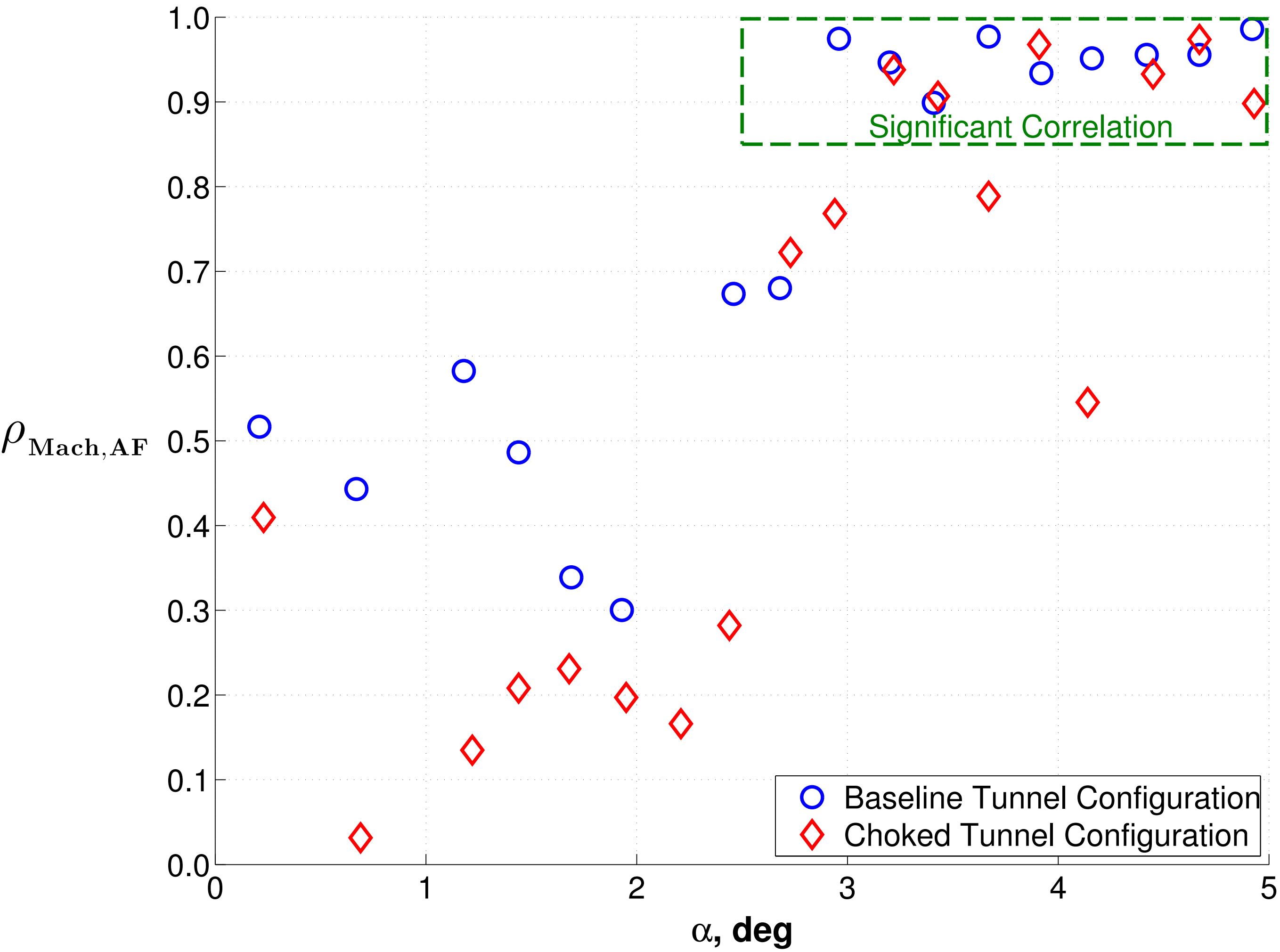
M_∞ = 0.85 at α=4° in CHOKED tunnel configuration from CRM test



Strong correlation between M_∞ and balance axial force

Reduction in balance axial force variability in addition to reduction in Mach number variability

M_∞ = 0.85 from CRM test



Significant correlation between M_∞ and balance axial force for $\alpha > 2.5°$

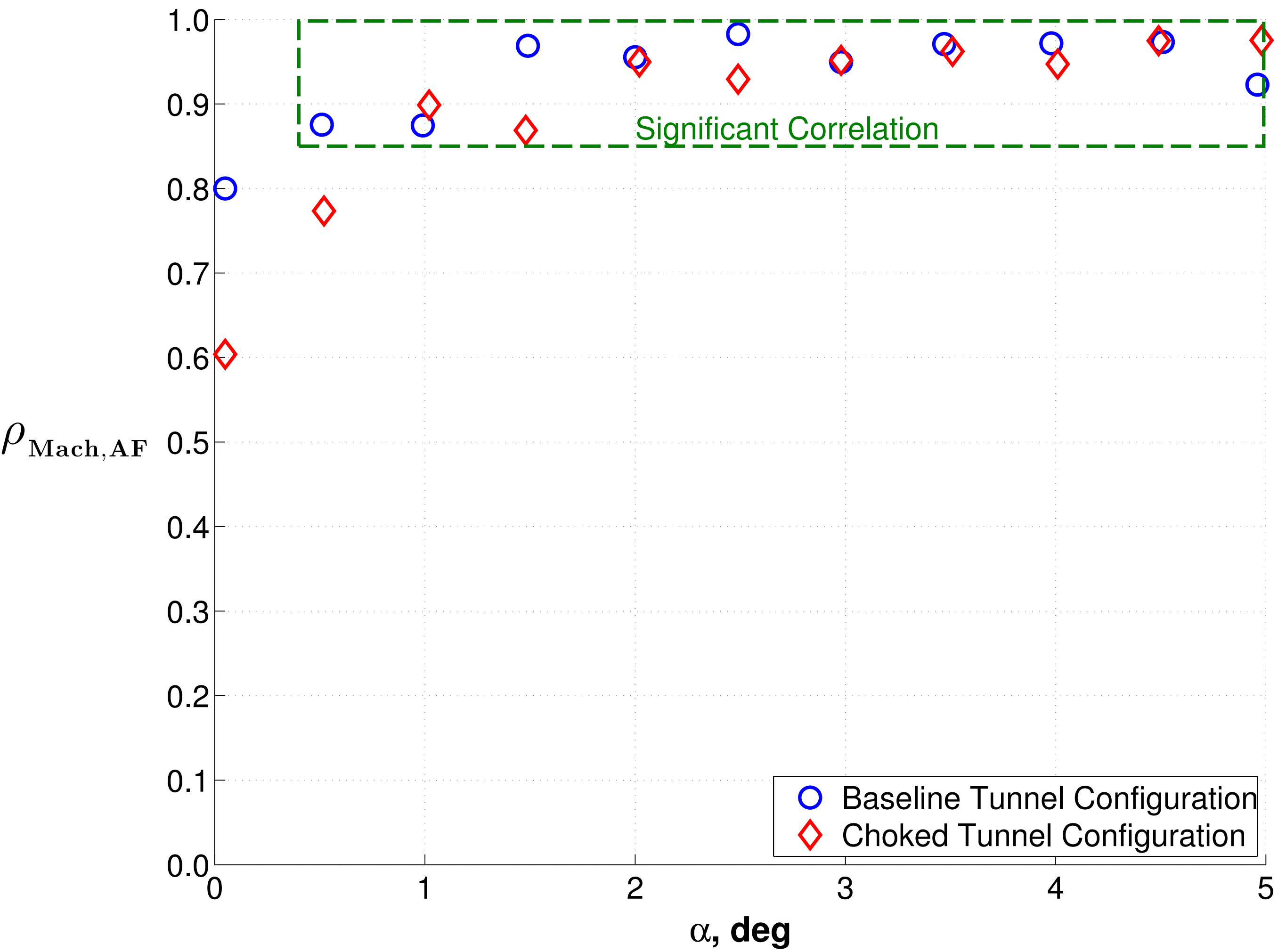
CRM wing designed for $C_L = 0.5$ at $M_\infty = 0.85$

$C_L = 0.5$ corresponds to $\alpha \approx 3°$ at $M_\infty = 0.85$

For CRM model at $C_L = 0.5$, drag divergence begins at around $M_\infty = 0.85$

Correlation Between Mach and Drag

M_∞ = 0.85 from PF-I test



Significant correlation between M_∞ and balance axial force for $\alpha > 0.5°$

PF-I wing designed for $C_L = 0.55$ at $M_\infty = 0.82$

For PF-I model, $M_\infty = 0.85$ is above drag divergence Mach number for most angles of attack

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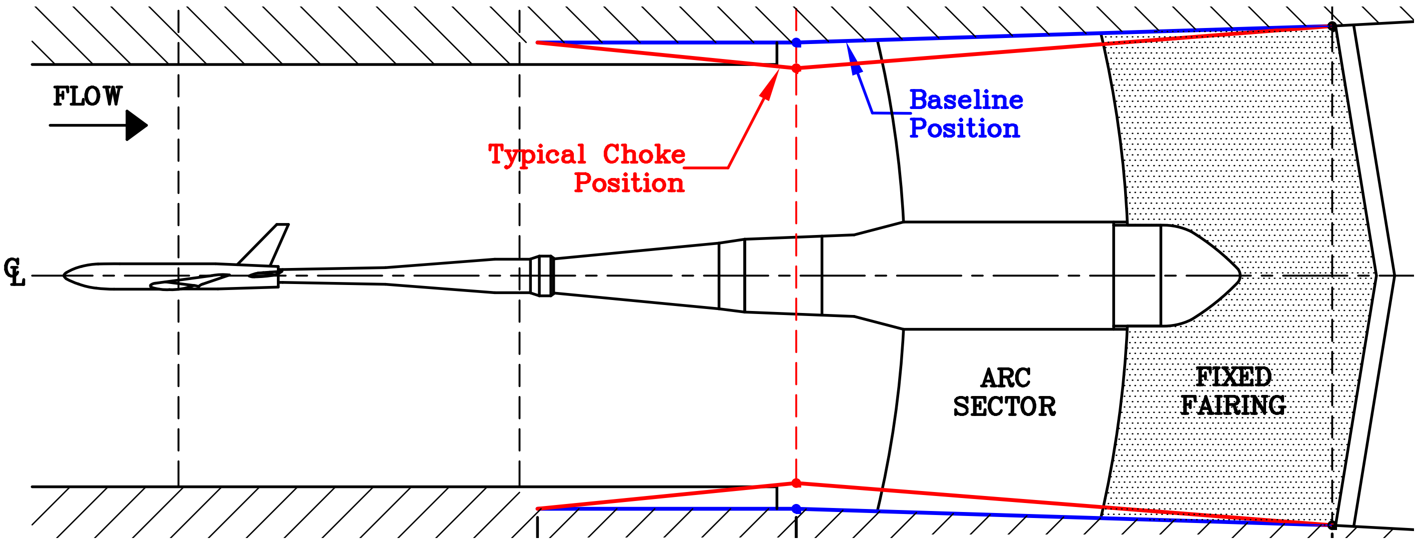
Consequences of Using Existing Throat

Possibility of increased model dynamics

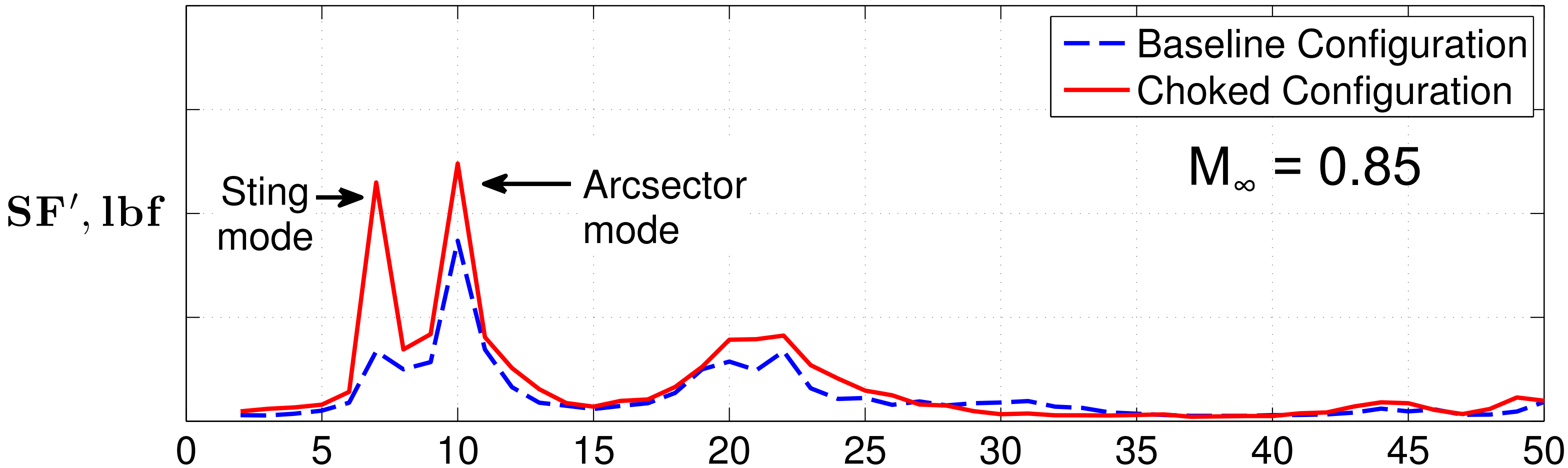
- Shock at second throat can excite known arc sector and sting dynamic modes

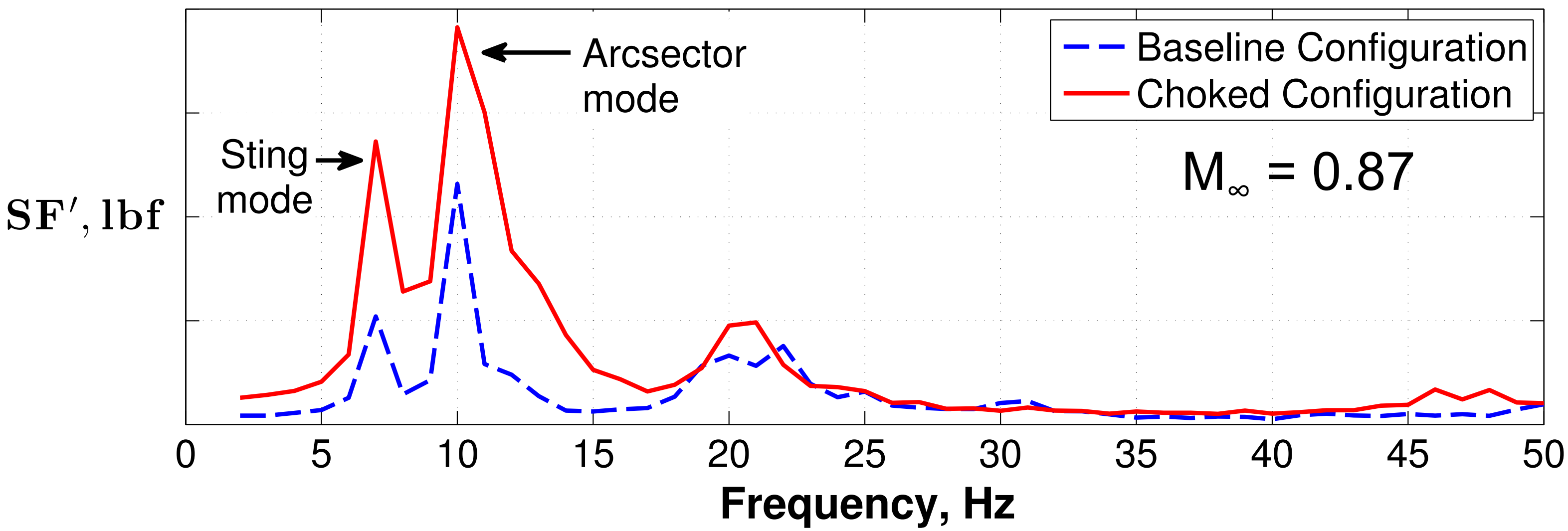


- As M_∞ approaches the choke Mach number and the shock strength at the second throat increases, model dynamics will also increase

- The increased model dynamics MAY negate any drag repeatability benefit gained from reduced Mach number variability

α = 4.5° from CRM test





Consequences of Using Existing Throat

Tunnel calibration changes

- Recent tunnel calibration check-out test showed there is a small effect to the calibrated test section Mach number and the Mach number distribution
- Follow-on work will be needed to update tunnel calibration for the choked tunnel configuration

Summary

Existing second throat capability at the NTF improves Mach stability

- Sonic conditions at throat were verified using sidewall pressure data
- 40-45% reduction in Mach variation levels at $M_\infty = 0.85$
- Variation levels reduce rapidly as M_∞ approaches choke Mach number

Mach variation trend with angle of attack also reduced

- Similar results with low frequency balance axial force fluctuations
- Trend is eliminated completely as M_∞ approaches choke Mach number

Strong correlation between M_∞ and AF in drag divergence region

- Improved Mach stability leads to drag repeatability improvements

Consequences of using existing second throat

- Possibility of increased model dynamics
- Effects on calibrated M_∞ and Mach number distribution

Concluding Remarks

Strategy for reducing drag repeatability levels to within ±0.5 counts

- Use existing <u>second throat</u> to improve Mach stability without large increase in model dynamics
  - ➢ Example : Run at $M_\infty = 0.85$ with choke setting for $M_\infty = 0.9$
- Use <u>conditional sampling</u> techniques to reduce remaining variation in Mach number and drag within a data point

Future work

- Update tunnel calibration for choked tunnel configuration
- Continue to investigate use of existing second throat
  - ➢ Different types of models (semi-span, non-lifting, etc.)
- Plans for installing new second throat downstream of arc sector